Reprinted from the *Soil Science Society of America Journal*
Volume 51, no. 5, September–October 1987
677 South Segoe Rd., Madison, WI 53711 USA

Effects of Furrow Dikes on Water Conservation and Dryland Crop Yields[1]

ORDIE R. JONES AND R. NOLAN CLARK[2]

ABSTRACT

Eliminating or reducing storm runoff in the Southern Great Plains can increase soil-water storage, decrease erosion, and increase crop yields. The primary objectives of this study were (i) to examine the potential of furrow dikes as a conservation practice to retain runoff and increase crop yields, and (ii) to examine the effects of furrow diking on sorghum [*Sorghum bicolor* (L.) Moench] and sunflower (*Helianthus annuus* L.) production. Analyses of 28 yr of runoff records show furrow diking has the potential to retain 25 to 30 mm of runoff annually. The maximum annual runoff retention by diking observed during the 14 crop years of research (three separate experiments conducted between 1980 and 1985) was 111 mm. The maximum increase in sorghum yield measured as a result of diking was 2.46 Mg/ha. Conditions responsible for maximum yield responses of sorghum to diking were: (i) annual cropping, (ii) large rainfall/runoff events occurring prior to or early in the growing season, and (iii) limited growing season precipitation. Diking increased annual cropped sorghum yields on graded and contour furrow treatments by 49 and 14%, respectively, whereas water use efficiencies were increased by 25 and 16%. Yields and water use efficiencies from diked treatments on graded and contour furrows were as great as yields and water use efficiencies from a leveled minibench treatment, indicating that from a crop production standpoint, furrow diking was as effective as land leveling in retaining runoff and increasing crop yields. Sunflower yields were increased significantly by diking during 1 yr out of 3 when sunflower was grown after 76 weeks of fallow, whereas sorghum yields were not affected by diking after fallow. Decreasing row spacing from 1.0 to 0.75 m resulted in a significant increase in the 3-yr avg yield of sorghum and sunflower of 1.0 and 0.14 Mg/ha, respectively, when grown after fallow, indicating that considerable opportunity for improving summer crop production may exist simply by changing to a narrow row spacing. A regression equation relating runoff from graded furrows to runoff from contour flat-tilled graded terraces showed increased runoff from graded furrows, particularly from small storms.

Additional Index Words: **runoff, basin tillage, basin listing, tied ridges, sorghum [*Sorghum bicolor* (L.) Moench], sunflower (*Helianthus annuus* L.).**

Jones, O.R., and R.N. Clark. 1987. Effects of furrow dikes on water conservation and dryland crop yields. Soil Sci. Soc. Am. J. 51:1307–1314.

MANY WATER CONSERVATION PRACTICES have been used through the years in attempts to increase dryland crop production in the semiarid Southern Great Plains. The most successful methods retain all precipitation, thus eliminating runoff and providing more water for crop production (Unger and Stewart, 1983). Land leveling is the most effective practice, but costs for leveling are expensive and fertility problems may develop when deep soil cuts are made (Jones et al., 1985b). An alternative to land leveling for retaining storm runoff is furrow diking, where small dikes or dams are constructed at intervals along furrows to retain potential runoff, thus allowing it to infiltrate.

Furrow diking, also known in the USA as furrow damming, basin tillage, basin listing, or microbasin tillage, was originated on the Great Plains in 1931 by C.T. Peacock, a wheat farmer at Arriba, CO (Chilcott, 1937). Tests of furrow diking were conducted at several Great Plains locations during the late 1930s and 1940s, including Lincoln, NE; Colby, Hays, and Garden City, KS; and Cherokee and Woodward, OK. These early tests, conducted primarily with wheat (*Triticum aestivum* L.), showed little or no consistent increases in yield (Daniel, 1950; Kuska and Mathews, 1956; Luebs, 1962; Musick, 1981). By 1950, furrow diking was generally abandoned because of slow operating speed of diking equipment, poor weed control, difficulty with seedbed preparation and subsequent tillage, and little benefit in yield.

Although the furrow diking concept originated in the U.S. Great Plains, considerable research has been conducted in the semiarid tropics of Africa, where the practice is called tied-ridging. The tied-ridge system reduced runoff and soil loss and, in many instances, has increased crop yields (El-Swaify et al., 1985; Lawes, 1966). However, during high rainfall years or rainy periods, tied-ridge systems may result in water logging and reduced crop yields (Dagg and Macarthey, 1968). The potential of tied-ridges to improve soil and water conservation and crop yields in Africa has been recognized, and equipment has been designed and procedures developed for their use (Constantinesco, 1976; Dagg and Macarthey, 1968).

In 1975, agricultural engineers with the USDA-ARS and the Texas A&M Agric. Exp. Stn. designed and built improved diking equipment and conducted field tests of diking (Lyle and Dixon, 1977; Clark and Jones, 1981). They hypothesized that furrow diking would conserve water and increase crop yields if a summer crop was grown and herbicides were used for weed control. Favorable responses to diking were obtained with grain sorghum [*Sorghum bicolor* (L.) Moench] and cotton (*Gossypium hirsutum* L.), and the practice was quickly adopted by farmers (Clark and Jones, 1981; Gerard et al., 1983a, b). By 1984, an estimated 800 000 ha were furrow-diked in the Southern Great Plains, primarily on land devoted to cotton (Wistrand, 1984).

Although furrow diking has been widely accepted in the Southern Great Plains for cotton, producers of other crops and in other regions may benefit from application of furrow dikes. The primary purposes of this paper are to examine the potential of furrow dikes to retain runoff in the Southern Great Plains, and to present and discuss the results of 14 crop years of research with dryland sorghum and sunflower (*Helianthus annuus* L.) production using furrow dikes. A secondary purpose is to examine the effects of row spacing on sorghum and sunflower production.

[1] Contribution from the USDA-ARS, Conservation and Production Res. Lab., P.O. Drawer 10, Bushland, TX 79012. Received 23 Oct. 1986.

[2] Soil Scientist and Agricultural Engineer, USDA-ARS, Conservation and Production Res. Lab., Bushland, TX 79012.

MATERIALS AND METHODS

Analysis of Water Conservation Potential

Precipitation and runoff data used in determining the water conservation potential of diking were obtained from a long-term (1958–1984) runoff study from graded terraces conducted at the USDA Conservation and Production Res. Lab., Bushland, TX. The semiarid climate, topography, and soils are typical of 5 million ha in Texas, Oklahoma, and New Mexico. Average annual precipitation at Bushland is 466 mm, and average 0.5-yr (April–September) evaporation from a free water surface is 1270 mm. The field-sized watersheds (2.1–3.8 ha) were cropped in a dryland winter wheat-sorghum-fallow sequence, and stubble mulch tillage was used to retain some crop residues on the soil surface to aid in wind erosion control. The soil is a slowly permeable Pullman clay loam (fine, mixed, thermic Torrertic Paleustoll), with a water-holding capacity of 230 mm of plant available water to the 1.8-m depth. Other details of the watersheds and precipitation and runoff measurements were described by Hauser et al. (1962), Jones (1975), and Jones et al. (1985a).

Furrow Diking Experiments

Experiment A was conducted for 3 yr (1980–1982) at the USDA Conservation and Production Res. Lab., Bushland, TX. Sorghum and sunflower were grown on adjacent blocks of land that had been fallow for 76 weeks. Each crop was grown in a randomized split-plot experiment with six replications. Main plot treatments were row spacings of 0.75 and 1.0 m, whereas subplot treatments were diked and open (undiked) furrows. Furrows were approximately 15 cm deep. Subplots were six rows wide with 0.75-m row spacings and four rows wide with 1.0-m row spacings. All plots and subplots were 150 m long. Land slope was 0.5%, and rows were directed up and down slope. Data for sorghum and sunflower were analyzed separately, using SAS (1985) analysis of variance (ANOVA) procedures.

Experiment B was conducted for 2 yr (1980–1981) on a Sherm clay loam (fine, mixed, mesic Torrertic Paleustoll) at the Texas A&M Univ. North Plains Research Field, Etter, TX, 100-km northeast of Bushland, TX. Treatments were diked and open furrows, and the treatments were maintained on the same plot areas for both years. Land slope was 0.5%, row spacing was 1 m, and plots were 8 m wide and 420 m long. The randomized block experiment with six replications was established on a field area cropped annually to sorghum. The soil-water content in the root zone was probably near wilting point in January 1980 when the experiment began.

Experiment C was conducted at the USDA-ARS Lab., Bushland, TX, from 1980 to 1985 to examine the effects of conjunctive use of furrow diking along with contour furrows, graded furrows, and leveled minibenches for conserving soil and water. The randomized split-plot experiment had three replications and was cropped annually to sorghum. Main plot treatments were contour furrows, graded furrows (0.25% slope), and leveled minibenches. These treatments were described by Jones (1981). Subplot treatments were diked and open furrows on the contour-furrow and graded-furrow plots, and diked furrows and flat tillage with sweeps on the minibench plots. Subplots contained 12 rows on a 1-m spacing and were 150 m long except on the minibench treatment, where each subplot was a separate level minibench four rows wide and 150 m long. Berms 0.35 m high around the perimeter of each minibench retained all precipitation.

Tillage operations for all experiments are summarized in Table 1. In all experiments, 'DK 42Y' or 'DK 46' hybrid sorghum seed (74 000 seed/ha) were planted in rows on top of the bed (except on the flat treatment) with planters having double disk openers. Intrarow seed spacings were adjusted in Exp. A so that approximately the same number of seed was planted per unit area, regardless of row spacing. Also, in Experiment A, USDA Hybrid 894 sunflower was planted at 44 000 seed/ha on top of the bed. Soil-water contents on all experiments were determined with the neutron method (one tube per plot or subplot on three replications) at planting and harvest. Measurements were taken to a 1.8-m depth by 30-cm increments. Runoff was measured with 30-cm "H" flumes and FW-1 water stage recorders from open (undiked) treatments on Exp. A, from both diked and open treatments on Exp. B, and from the open treatment on graded furrows on Exp. C. Grain or seed yields were obtained by hand-harvesting samples from 12-m sections of the center rows, with two harvest samples taken per plot except on the minibench plots, where 6-m sections of all four rows were in-

Table 1. Summary of cultural operations.

Date	Experiment A (1980–1982)	Experiment B (1980–1981)	Experiment C (1980–1985)
Late March or early April	Apply trifluralin at 2.3 l/ha to sunflower plots and disk to incorporate	--	--
	List (corrugate) to form beds and furrows	Disk and list (corrugate) to form beds and furrows	Disk contour furrow, graded furrow, and diked minibench treatments, sweep flat-tilled minibench treatment
			List (corrugate) to form beds and furrows
Mid- to late April	Rolling cultivate	Rolling cultivate	Rolling cultivate or sweep
	†Furrow dike and apply 1.7 kg/ha terbutryn to sorghum plots	Furrow dike	†Furrow dike
	Install "H" flumes on open treatments	†Install "H" flumes on diked and open treatments	Install "H" flumes on graded furrows (open)
Early to mid-June	Rolling cultivate	Rolling cultivate	Apply glyphosate at 0.56 kg/ha
	Plant sunflower and sorghum	Plant sorghum	Apply metolachlor (2.2 kg/ha) and propazine‡ (2.2 kg/ha)
	†Furrow dike sorghum and sunflower and apply 1.1 kg/ha terbutryn on sorghum	† Furrow dike and apply 2.2 kg/ha propazine	Plant sorghum (CGA-43089 Safened seed)§
Late September	Harvest sunflower	--	--
Late October and early November	Harvest sorghum	Harvest sorghum	Harvest sorghum

† Furrow dikes were constructed with commercially manufactured single-paddle wheel-type diking units that formed dikes at 2.1-m intervals.
‡ 2-Chloro-4,6-bis(isopropylamino)-*s*-triazine.
§ CGA-43089 is a seed dressing to protect grain sorghum from the phytotoxic effects of metolachlor. [2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl) acetamide].

cluded in the harvest sample. Samples were threshed in a stationary thresher, and sorghum and sunflower yields are reported at 13 and 9% moisture, respectively.

Yields reported on the minibench treatment have been adjusted 20% downward to account for the plot area occupied by the berm, which is an integral part of the minibench soil and water conservation system.

Water use efficiencies (WUE) reported for Exp. B and C were determined using procedures described by Unger (1978),

$$\mathrm{WUE} = \text{grain yield}/(\mathrm{SW_p} - \mathrm{SW_h} + \mathrm{P}) .$$

where SW_p and SW_h are soil-water contents to a 1.8-m depth measured at planting and harvest, respectively, and P is growing season precipitation.

A monthly summary of precipitation and runoff at Bushland, TX, is shown in Fig. 1 for the experimental period, 1980 to 1985.

RESULTS AND DISCUSSION

Potential

The potential of furrow dikes to retain runoff and increase crop yields depends on: (i) rainfall (amount, intensity, seasonal distribution), (ii) soil characteristics that influence runoff (primarily infiltration rate) and soil-water storage, and (iii) capacity of the dikes to hold water. In the Southern Great Plains, most rainfall and runoff occurs from May through August, as shown for Bushland, TX, in Fig. 1. The crop grown also affects runoff. More than twice as much runoff was measured from sorghum and the fallow period after sorghum as was measured from wheat and the fallow period after wheat in a dryland wheat-sorghum-fallow sequence (Fig. 2). Thus, the potential for retaining runoff with furrow dikes is much greater with sorghum or a summer crop than with wheat. Runoff values from wheat are low because wheat depletes most of the soil water by May or June and shrinkage cracks result in very high water infiltration rates and little runoff during the high rainfall months. Conversely, with summer crops planted in May or June, soil-water contents are usually high near the surface at seeding and soils are not cracked, resulting in a low water infiltration rate, thus promoting runoff when high intensity storms occur. The terminal water infiltration rate on the Sherm and Pullman soils averages 2.2 mm/h, whereas rainfall intensities in excess of 75 mm/h are common for short periods of time (Table 2). Thus, the potential for large losses of water to storm runoff exists, particularly when antecedent storms have occurred.

High intensity storms with total rainfall amounts >51 mm account for only 9% of total precipitation

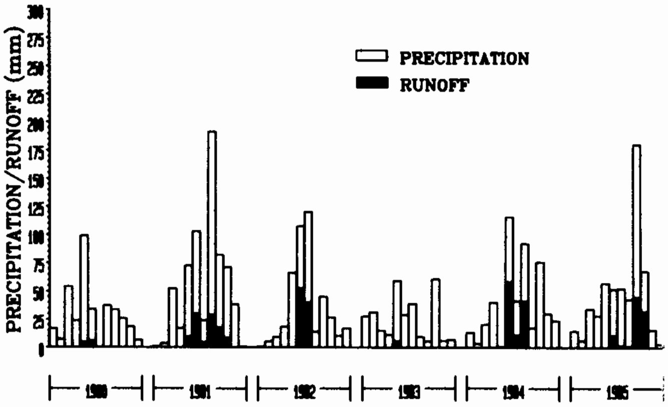

Fig. 1. Monthly precipitation and runoff measured from the graded furrow, open (no dikes) treatment, Exp. C, Bushland, TX, 1980 to 1985.

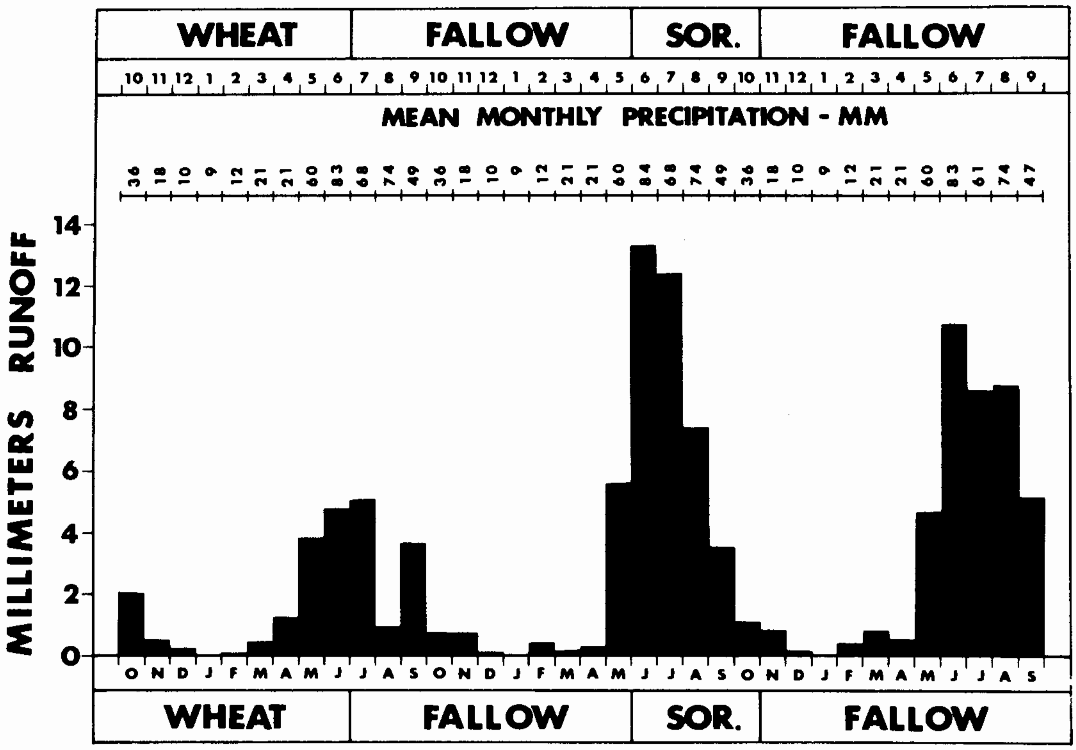

Fig. 2. Twenty-six year mean monthly precipitation and runoff from a dryland wheat-sorghum-fallow sequence with stubble-mulch tillage, Bushland, TX, 1958 to 1983 (from Jones et al., 1985a).

Table 2. Precipitation, runoff, and maximum precipitation intensity measured from large, intense storms (>51 mm), Bushland, TX, 1958–1985 (28 yr).

Date	Precipitation	Runoff from watersheds: Wheat	Sorghum	Fallow	Maximum intensity: 5 min	10 min	60 min
	mm				mm/h		
16 Dec. 1959	54	3	4	6	--†	--	--
8-9 Sept. 1960	58	0	24	14	55	47	29
13 July 1963	65	16	36	32	167	143	54
10-11 June 1965	59	13	28	29	74	57	12
24-25 June 1965	80	42	56	54	99	96	41
17-18 Aug. 1971	69	4	25	17	79	79	30
21-22 Sept. 1971	60	6	15	10	26	26	11
29 June 1972	65	0	29	24	104	104	55
4 May 1974	53	9	T‡	T	77	77	41
24 May 1974	52	11	T	T	90	89	38
22-23 July 1975	51	0	18	T	50	49	27
11 Aug. 1977	78	T	12	28	81	81	42
26 May 1978	89	55	52	47	104	104	61
19 Sept. 1978	120	38	56	55	107	102	57
30 July 1982	94	33	49	33	--	--	--
13 June 1984	96	28	44	86	--	--	--
12 Sept. 1985	84	3	7	29	--	--	--
Total (large storms)	1 228	263	458	463			
Total (all storms)	13 067	578	1 225	1 218			
Percent of 28-yr total	9	45	37	38			
Annual avg.	467	21	44	43			

† Precipitation intensity data not available for these storms.
‡ T = trace amount of runoff, <0.5 mm.

at Bushland, but they account for 40% of total runoff (Table 2). Thus, for furrow dikes to be effective, they must retain water from these large storms. The dikes that we constructed for these experiments, using commercially available equipment, had a calculated surface storage capacity, based on profile measurements, of approximately 50 mm on a 0.75-m row spacing and 60 mm on a 1.0-m row spacing. Thus, depending on antecedent soil-water conditions, initial infiltration rates, and characteristics of the storm (intensity and duration), potential runoff from 50- to 100-mm storms can be retained with well-constructed furrow dikes. Furrow dikes retained all precipitation from a 150-mm storm when the soil profile was dry and initial infiltration rates were high (Clark and Jones, 1981).

For a wheat-sorghum-fallow crop sequence with contour stubble mulch tillage, long-term runoff data from Bushland show that there is a 50% probability of losing 30 mm of runoff annually from sorghum, 25 mm from fallow after sorghum, and 12 mm from wheat (Fig. 3). Anticipated average yield response to an additional 25 mm of water is 0.38 Mg/ha for sorghum (Stewart, 1985) and 0.17 Mg/ha for wheat (O.R. Jones, 1986, unpublished data). These values reflect the potential annual yield responses of sorghum and wheat that we might expect over the long-term from furrow diking. Crop yield response to furrow diking may be much greater, as we show in Exp. B and C, when compared with tillage practices such as corrugation up and down slope or clean tillage, which promote runoff. Crop yield responses to diking will be highly variable from year to year in the Southern Great Plains because in 15% of the years, no runoff is expected, and in 7% of the years, runoff exceeds 100 mm during the sorghum growing season and during fallow after

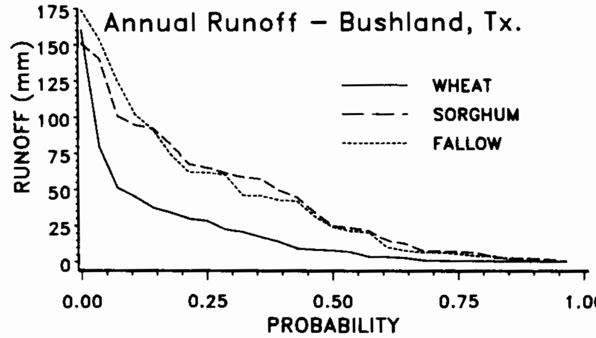

Fig. 3. Probability of receiving a specified volume of storm runoff for a dryland wheat-sorghum-fallow cropping sequence that received stubble mulch tillage. Based on 27 yr of runoff records, Bushland, TX, 1958 to 1984.

sorghum. The maximum annual runoff observed from watersheds cropped to sorghum during the 28 yr of record (1958 to 1985) was 150 mm in 1978.

Experiment A

The effects of furrow diking and row spacing on dryland sorghum and sunflower yield and yield components are shown in Table 3.

Sorghum

Furrow dikes did not significantly increase yield of sorghum during any year of the experiment. Little precipitation and runoff occurred during the 1980 growing season; and with no rainfall in July, crop yields were very low. In 1981, July was very dry, but beginning in August, runoff was retained by diking; however, precipitation, with or without diking, supplied adequate water for the remainder of the growing season and resulted in high yields. Since crops were planted on fallow fields each year, the carry-over effect of late season runoff retention in 1981 was not evaluated for the next crop. In 1982, high intensity storms with large runoff occurred, but runoff retention with diking did not increase yields because plant needs were met with water stored at planting and with timely rainfall. The diking treatment did not significantly affect any yield components during any year of the experiment.

Row spacing exerted a large effect on sorghum yield in both 1981 and 1982, primarily through its effect on tillering. The late season rainfall in 1981 resulted in more tillers on plants in 0.75-m spaced rows than in 1.0-m spaced rows. The increased number of tillers (as reflected by a 55 and 60% increase, respectively, in number of heads harvested per hectare for 1981 and 1982, Table 3) plus excellent late season rainfall amount and distribution and late frosts resulted in increased grain yields in both 1981 and 1982 for sorghum grown on the 0.75-m spaced rows. Although the seed weight yield component was significantly greater on 1.0-m spaced rows, the increased tillering on 0.75-m spaced rows more than offset the seed weight effects.

The extensive late season tillering observed in 1981 and, to some degree, in 1982, was highly unusual; we are hesitant, based on the results of this 3-yr experiment, to conclude that narrow row spacing will result

Table 3. Effects of furrow dikes and row spacing on yield and yield components of sorghum and sunflower grown after fallow, Exp. A, Bushland, TX, 1980 to 1982.

	Sorghum				Sunflower			
	1980	1981	1982	Mean	1980	1981	1982	Mean
	grain yield, Mg/ha				Seed yield, Mg/ha			
Open furrows	1.03	3.64	3.41	2.69	0.86	1.46	1.10*	1.14*
Diked furrows	1.28	3.62	3.55	2.82	0.90	1.46	1.30*	1.22*
1.0-m row spacing	1.08	2.90***	2.74***	2.24***	0.78*	1.37*	1.16	1.11**
0.75-m row spacing	1.23	4.36***	4.22***	3.27***	0.99*	1.52*	1.24	1.25**
CV	33.1	15.7	7.0	9.6	21.1	11.8	17.3	6.9
	no. of heads/m^2				no. of heads/m^2			
Open furrows	4.46	10.51	8.12	7.70	3.57	3.19	3.73	3.50
Dicked furrows	4.99	10.30	7.65	7.65	3.71	3.01	3.36	3.36
1.0-m row spacing	4.41	8.13***	6.02***	6.19***	3.31	2.93	2.90***	3.05**
0.75-m row spacing	5.05	12.68***	9.75***	9.16***	3.97	3.27	4.18***	3.81**
CV	20.7	15.1	12.6	10.8	20.6	15.0	14.8	10.7
	seed weight, mg/seed				seed weight, mg/seed			
Open furrows	--†	25.5	24.8	25.2‡	--†	33.7*	37.8	35.8*‡
Dicked furrows	--	25.3	25.7	25.5	--	36.3*	38.9	37.6*
1.0-row spacing	--	25.5	26.9*	26.2**	--	35.1	40.5*	37.8**
0.75-m row spacing	--	25.4	23.6*	24.5**	--	34.9	36.2*	35.6**
CV	--	3.17	5.09	3.34	--	7.36	10.1	4.04
	no. of seed/head				no. of seed/head			
Open furrows	--†	6830	9130	7980‡	--†	6920	4110*	5510‡
Diked furrows	--	7150	9450	8300	--	6860	5110*	5990
1.0-m row spacing	--	7070	8960	8015	--	7000	5000	6000
0.75-m row spacing	--	6910	9630	8270	--	6780	4210	5500
CV	--	14.8	14.4	12.0	--	17.7	29.0	12.1
	mm				mm			
Growing season precip.	98	469	365		68	400	365	
Growing season runoff (Open treatments)	0	63	53		0	63	53	

*,**,*** Mean values within a treatment were significantly different at the 0.05, 0.01, and 0.001 probability levels, ANOVA, respectively. Means without asterisks were not significantly different from the corresponding mean at the 0.05 level. The diking treatment × row spacing interaction was not significant at the 0.05 level for any factor for any year.

† Data for this factor were not taken in 1980.

‡ Two-year mean.

in long-term increases in sorghum yield on dryland, but that possibility certainly exists.

Sunflower

Furrow diking increased sunflower yield in 1982 but had no significant effect in 1980 and 1981. Retention of 53 mm of runoff from storms on 26 and 30 June 1982 resulted in the 0.2 Mg/ha yield increase on the diked treatment. Yield increase due to diking in 1982 was small because plant water requirements were provided by stored soil water and favorable rainfall during the growing season. No runoff occurred during the 1980 growing season. In 1981, when runoff occurred late in the growing season, diking did not affect sunflower yields because precipitation amounts were large enough to supply plant water needs with or without runoff retention with dikes. The yield component responsible for the yield increase due to diking in 1982 was the number of seed per head.

Decreasing row spacing from 1.0 to 0.75 m significantly increased sunflower seed yields in 1980 and 1981. Although the increases are not of the magnitude observed for sorghum, the tendency for increased yield on the narrow row spacing was consistent, which supports a hypothesis that a more even distribution of sunflower plants over the ground surface may improve dryland sunflower production. Plant survival to anthesis was enhanced with or by the narrow row spacing, as evidenced by increased numbers of heads harvested per unit area. As for sorghum, seed weight for sunflower tended to be greater on 1.0-m spaced rows.

Table 4. Effect of furrow dikes on sorghum yield, runoff, and water use efficiency of annual cropped grain sorghum, Experiment B, Etter, TX, 1980 to 1981.

	Sorghum yield		WUE (grain)†		Growing season precipitation		Runoff	
	1980	1981	1980	1981	1980	1981	1980	1981
	Mg/ha		kg/m^3		mm			
Diked furrows	2.33	2.63	1.16	1.16	73	250	61‡	0
Open furrows	0.64	1.40	0.37	0.55	73	250	130	88
Difference	**	**	**	**				

** Mean values are significantly different at the 0.01 probability level, ANOVA.

† Water use efficiency based on grain yield, growing season precipitation, and changes in soil-water content between planting and harvest.

‡ On 27 May 1980 prior to sorghum seeding, a 148-mm storm resulted in runoff losses of 61 and 107 mm from diked and open furrows, respectively.

Experiment B

The results of Experiment B demonstrate the potential capacity of furrow diking to conserve water and increase sorghum yield and water use efficiency (Table 4). Yields were increased 264 and 87% in 1980 and 1981, respectively, by furrow diking. Runoff retained by furrow dikes was used very efficiently, producing

Table 5. Effect of furrow diking on sorghum yield and water use efficiency† with contour furrows, graded furrows, and minibench conservation treatments. Experiment C, Bushland, TX, 1980–1985.

Conservation practice	Diking treatment	Year 1980	1981	1982	1983	1984	1985	Mean
		sorghum yield, Mg/ha						
Contour furrow	Open	0.55	3.23	4.46	1.73	1.20	0.73	1.98
Contour furrow	Dike	0.71	3.55	4.58	1.74	1.91	1.05	2.25
Difference		NS‡	NS	NS	NS	*	**	*
Graded furrow	Open	0.24	2.81	2.43	1.97	1.13	0.71	1.55
Graded furrow	Dike	0.02	3.74	4.89	2.30	2.03	0.91	2.31
Difference		*	*	**	NS	**	NS	***
Minibench	Flat	1.02	2.68	4.16	1.52	1.80	1.30	2.08
Minibench	Dike	1.06	3.06	3.96	1.84	1.92	1.19	2.17
Difference		NS	NS	NS	*	NS	NS	NS
		water use efficiency (grain), kg/m^3						
Contour furrow	Open	0.29	0.68	1.18	1.02	0.43	0.19	0.63
Contour furrow	Dike	0.36	0.86	1.24	1.10	0.58	0.26	0.73
Difference		NS	*	NS	NS	NS	**	*
Graded furrow	Open	0.13	0.64	0.83	1.43	0.39	0.16	0.60
Graded furrow	Dike	0	0.90	1.18	1.46	0.69	0.25	0.75
Difference		*	*	*	NS	**	NS	*
Minibench	Flat	0.50	0.68	0.98	0.82	0.54	0.31	0.64
Minibench	Dike	0.57	0.76	0.95	1.02	0.56	0.29	0.69
Difference		NS	NS	NS	*	NS	NS	NS
		mm						
Runoff§		0	91	93	6	111	92	66
Annual precipitation		355	662	446	379	464	553	476

*,**,*** Mean values were significantly different at the 0.05, 0.01, and 0.001 probability levels, ANOVA, respectively.
† Water use efficiency based on grain yield, growing season precipitation, and changes in soil-water content between planting and harvest of sorghum.
‡ NS = means were not significantly different at the 0.05 level.
§ Runoff measured from graded furrows without furrow dikes (open treatment).

2.4 and 1.4 kg grain/m^3 of retained water in 1980 and 1981, respectively.

Environmental and crop management factors that resulted in the large yield responses to retained runoff were (i) continuous cropping, which did not allow the soil-water content of the root zone to be replenished during the noncrop period; (ii) large rainfall/runoff events that occurred immediately prior to or early in the growing season with furrow dikes in place to capture runoff, thus resulting in differential soil-water contents between treatments; and (iii) limited growing season precipitation, which increased reliance on stored soil water.

Experiment C

The effects of furrow diking on sorghum yield and water use efficiency for the conservation practices of contour furrows, graded furrows, and minibenches are shown in Table 5. We chose this simplified method to present the data since a split-plot ANOVA showed the conservation practice × diking treatment interaction terms for yield to be significant in 1982, 1985, and for the 6-yr mean.

Furrow diking increased 6-yr mean grain yields on graded furrows, contour furrows, and minibenches by 49, 14, and 4%, respectively. The 4% increase on minibenches was not statistically significant.

On the graded-furrow treatment, diking increased sorghum yield significantly in 1981, 1982, and 1984, and the 6-yr mean yield was increased 0.76 Mg/ha. Yield increases on graded furrows were due to large volumes of runoff retained by diking during these years (Table 5).

Runoff volume was again large in 1985, but a significant yield increase due to diking was not observed on the graded furrows because an early freeze (30 September) stopped plant development prior to physiological maturity. The largest yield increase (2.46 Mg/ha in 1982) on graded furrows resulted from timely retention of growing season runoff with dikes plus a carry-over of soil water conserved with dikes from late season runoff in 1981.

Diking also resulted in increased sorghum yields on contour furrows, but the 6-yr mean increase was only 0.27 Mg/ha, about one-third of the average increase measured on graded furrows (Table 5). Some runoff loss occurred from contour furrows (open treatment) because the ends of the furrows were not blocked. The runoff loss from contour furrows (open treatment) was not measured, but it was large enough so that runoff retention with furrow dikes did result in significant yield increases in 1984 and 1985.

On the minibench treatment, furrow diking did not affect sorghum yields significantly because plots were leveled and all runoff was retained with berms on both the diked and flat treatments. We believe it is of considerable importance that there was little difference in yield among the diked or open treatments on minibenches or the diked treatments on contour or graded furrows. From this we conclude that from a crop production standpoint, diking is as effective as land leveling for retaining runoff and increasing crop yields.

In water deficit areas, water use efficiency often is used as a measure to compare treatments or farming systems. In this study, the use of furrow dikes to retain runoff with annually cropped sorghum resulted in water use efficiency (for grain production) increases of 25, 16, and 8% on the graded furrows, contour fur-

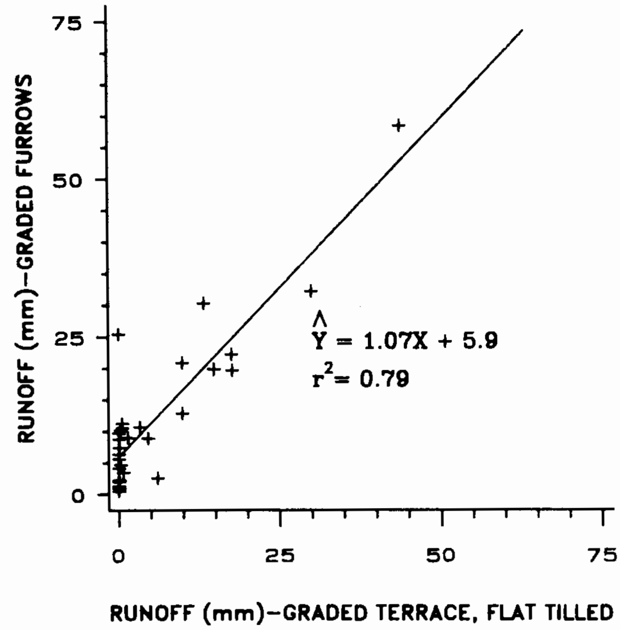

Fig. 4. Relationship of storm runoff volume from sorghum grown on graded furrows (0.25% slope) to runoff volume from sorghum grown in the sorghum phase of a wheat-sorghum-fallow sequence on nearby graded terraces with flat, stubble-mulch tillage, Bushland, TX, 1980 to 1985.

Fig. 5. Retention of storm runoff with furrow dikes on the graded furrow treatment, Exp. C, Bushland, TX, June 1984.

rows, and minibench conservation treatments, respectively. As with grain yield, the increase on minibenches was not statistically significant (Table 5).

The relationship of runoff measured from sorghum grown on graded furrows and on nearby graded terraces with stubble mulch tillage on the contour shows increased runoff from graded furrows, particularly for small storms (Fig. 4). Long-term runoff data are not available from graded furrows, but 28 yr of data are available for areas cropped to sorghum in a wheat-sorghum-fallow sequence. Application of the developed relationship to long-term data should provide a reasonable projection of runoff from graded furrows, which in turn may be of benefit to crop and climatic system modelers.

GENERAL DISCUSSION

The runoff retention capacity of dikes will vary, depending on soil type, row spacing, and equipment used to construct dikes. On coarse soils with high infiltration rates, paddle-type dikers having two or three paddles are commonly used that make a dam approximately every meter with a capacity to retain up to 25 mm of water. On fine-textured soils, dikes with a 50- to 60-mm retention capacity are constructed, as shown in Fig. 5, using single-paddle equipment. This type of equipment was used in the experiments reported here and is commercially available.

The effectiveness of furrow dikes in retaining runoff and preventing erosion from large storms is affected also by land slope and "preconditioning." In Ochiltree County, Texas, 70 mm of rainfall in 0.5 h overtopped newly constructed furrow dikes, resulting in moderate erosion on the 3% sloping clay soil (O.R. Jones, 1979, unpublished data). At Etter, TX, in May 1980 (Exp. B), 148 mm of rain fell in <24 h. Furrow dikes on the 0.5% sloping clay loam overtopped but did not erode appreciably because the dikes had been settled or preconditioned by 25 mm of rainfall that occurred 2 weeks prior to the large storm. The authors' experience with furrow diking shows that dikes constructed on gentle slopes and clay loam soils can effectively control or prevent erosion from large storms. For slopes >2%, we recommend that dikes be used in conjunction with other runoff control practices, such as terracing.

Wistrand (1984) reported the net economic benefit of furrow diking on annually cropped sorghum on graded furrows at Etter in 1980 (Exp. B) was U.S. $165/ha, while the 5-yr (1975–1979) average benefit of diking fallow sorghum at Bushland was $34.70/ha. He also reported diking costs to be only $2.15/ha when diking was performed simultaneously with listing, planting, or cultivation. However, he did not point out that benefits due to diking may be reduced if diking is delayed until cultivation. When performed as a separate operation, diking costs would be approximately $12.35/ha.

A large increase in yield is not required for diking to be economical. However, care must be used in evaluating yield increases because diking may retain runoff and increase yield when compared with an undiked graded furrow treatment, but when compared with production from other water conservation practices such as stubble-mulch or no-till, yields may not be increased by diking.

Furrow dikes have the advantage of preventing or reducing runoff and can potentially increase crop yield and produce an economic benefit; however, there are some disadvantages to diking. One disadvantage is that dikes must be rebuilt after each cultivation or tillage operation. Use of herbicides helps overcome this problem. Another disadvantage is that diking makes crop harvest more difficult. With cotton, dikes often are not replaced after the lay-by cultivation or special plowout units are mounted in front of wheels on the cotton stripper. In sorghum, combine tires may be spaced to operate on top of the bed. Also, aerial application of pesticides may be required, although some operators leave two furrows undiked on each pass to accommodate ground spray rigs.

REFERENCES

Chilcott, E.F. 1937. Preventing soil blowing on the Southern Great Plains. USDA Farmers Bull. 1771.

Clark., R.N., and O.R. Jones. 1981. Furrow dams for conserving rainwater in a semiarid climate. p. 198–206. *In* J.C. Siemens (ed.) Proc. Crop Production with Conservation in the 1980s, Chicago, IL. Dec. 1980. American Society of Agricultural Engineers, St. Joseph, MI.

Constantinesco, I. 1976. p. 52–62. Soil conservation for developing countries. FAO Soils Bull. 30. Rome.

Dagg, M., and J.C. Macarthey. 1968. The agronomic efficiency of the NIAE mechanized tied ridge system. Exp. Agric. 4:279–294.

Daniel, H.A. 1950. Water conservation for wheat production in Oklahoma. Soil Sci. Soc. Am. Proc. 15:408–412.

El-Swaify, S.A., P. Pathak, T.J. Rego, and S. Singh. 1985. Soil management for optimized productivity under rainfed conditions in the semiarid tropics. *In* B.A. Stewart (ed.) Advances in soil science, Springer Verlag, New York. 1:1–64.

Gerard, C.J., P. Sexton, L.E. Clark, and E.C. Gilmore, Jr. 1983a. Sorghum for grain: Production strategies in the Rolling Plains. Texas Agric. Exp. Stn. Bull. 1428.

Gerard, C.J., P.D. Sexton, and D.M. Matus. 1983b. p. 1–16. Furrow diking for cotton production in the Rolling Plains. Texas Agric. Exp. Stn. Consolidated Prog. Rep. 4174–4176.

Hauser, V.L., C.E. Van Doren, and J.S. Robins. 1962. A comparison of level and graded terraces in the Southern High Plains. Trans. ASAE 5:75–77.

Jones, O.R. 1975. Yields and water-use efficiencies of dryland winter wheat and grain sorghum production systems in the Southern High Plains. Soil Sci. Soc. Am. Proc. 39:98–103.

Jones, O.R. 1981. Land forming effects on dryland sorghum production in the Southern Great Plains. Soil Sci. Soc. Am. J. 45:606–611.

Jones, O.R., H.V. Eck, S.J. Smith, G.A. Coleman, and V.L. Hauser. 1985a. Runoff, soil, and nutrient losses from rangeland and dry-farmed cropland in the Southern High Plains, J. Soil Water Conserv. 40:161–164.

Jones, O.R., P.W. Unger, and D.W. Fryrear. 1985b. Agricultural technology and conservation in the Southern High Plains. J. Soil Water Conserv. 40:195–198.

Kuska, J.B., and O.R. Mathews. 1956. Dryland crop-rotation and tillage experiments at the Colby (Kansas) Branch Experiment Station. USDA Cir. 979. U.S. Government Printing Office, Washington, DC.

Lawes, B.A. 1966. Rainfall conservation and the yields of sorghum and groundnuts in northern Nigeria. Exp. Agric. 2:139–146.

Luebs, R.E. 1962. Investigation of cropping systems, tillage methods and cultural practices for dryland farming at the Fort Hays (Kansas) Branch Experiment Station. Kansas Agric. Exp. Stn. Bull. 449.

Lyle, W.M., and D.R. Dixon. 1977. Basin tillage for rainfall retention. Trans. ASAE 20:1013–1017.

Musick, J.T. 1981. Precipitation management techniques—new and old. p. 13–29. *In* D.D. Smith (ed.) Annu. Groundwater Manage. District Conf., 8th, Lubbock, TX. December 1981. High Plains Underground Water Conservation District no. 1, Lubbock, TX.

SAS Institute. 1985. SAS user's guide: Statistics. SAS Inst., Cary, NC.

Stewart, B.A. 1985. Limited irrigation-dryland farming systems. Proc. ICRISAT Workshop Manage. of Vertisols for Improved Agric. Production, February, 1985, Patancheru, India. ICRISAT, Patancheru, India.

Unger, P.W. 1978. Straw-mulch rate effect on soil water storage and sorghum yield. Soil Sci. Soc. Am. J. 42:486–491.

Unger, P.W., and B.A. Stewart. 1983. Soil management for efficient water use: An overview. p. 419–460. *In* H.M. Taylor et al. (ed.) Limitations to efficient water use in crop production. American Society of Agronomy, Madison, WI.

Wistrand, G.L. 1984. Furrow dike water conservation practices in the Texas High Plains. USDA Tech. Bull. 1691. U.S. Government Printing Office, Washington, DC.